Sensors Configuration for Small Scale Autonomous Ground Vehicle

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Abstract

This paper presents a small scale autonomous ground vehicle which is configured using sensors. The autonomous small scaled vehicle has been engineered to have dynamic behaviours equivalent with real ground vehicle. The main objective of the using sensors configuration is to obtain the dynamic behaviour of scaled vehicle. Sensors configuration are equipped with electronic instruments, Arduino Duemilanove, wireless communication system, data acquisition system, and numerous sensors. This study is conducted by simulation and experiment.

Keywords

Sensors, Arduino Duemilanove, Data Aquisition System, and Autonomous Small Scaled Vehicle

Introduction

The scaled vehicle dynamics represents an overview of the vehicle and environmental characteristics that contribute to successfully modeling and controlling vehicle dynamic behavior. The input of this model is the steering angle of the front wheels and rotational velocities of the rear drive wheels (Lukowski & Ravikumar, 1993). It delivers a 3 DOF output in terms of CoG vehicle velocity, body slip angle, and the yaw rate of the vehicle in x-y plane (Maček *et al*., 2007). The purpose of using a scaled vehicle dynamic is to show whether the vehicle dynamic behaviors are equivalent to those of real vehicle.

The study of the dynamic behaviours using of scaled vehicle as mentioned above was previously carried out through the testing conducted on a moving road surface (treadmill) (Brenan *et al*., 1998;1999) based on the position and orientation basis of the vehicle (Brennaman & Alleyne, 2001). In addition, the testing conducted is based on the scaled vehicle construction, such as the 1:5 scaled vehicle that is installed with a camera to measure position and orientation (Van Maren & Sika, 2011), the 1:10 scaled vehicle that is equipped with external camera to measures planar positions (Hoblet, 2003) and operated on a tilting treadmill which can create a 25deg in rolling axis (Glumac, 2006). Specifically, the conducted test on the 1:10 scaled vehicle is also towards the longitudinal response (Verma *et al*, 2008) and to the platform that is powered by an electric motor with 4 speed transmission (Witaya *et al*., 2009).

Based on this reason, this study is conducted to a small scaled vehicle on 3 degree of freedom (DOF) towards yaw rate, lateral acceleration, and roll velocity. While to determine the three degree of freedom motions, sensors are employed as the measuring device. The sensors used in this study is to determine the input and output for testing carried out.

All inputs were recorded using a data acquisition system due to its capabilty to record more than one of sensors input for verification. The output sensors were installed on microcontroller board with a wireless receiver.

To read the data obtained, the microcontroller chip is installed by the programme made using Microsoft Visual Studio C # software. The data is transmitted to the computer using the microcontroller receiver which is connected to the computer through the USB port. All the results obtained from the experiment is plotted into the graph. Based on these results, the comparison is carried out to the data based on the experiment conducted to the simulations using CarsimEd software.

Vehicle Model

According to the Wong (2001), the 3-DOF transient response model system can be derived from

mathematical equation. Kim and Ryu (2008) used the method to estimate the vehicle sideslip angle that contains of the transient response characteristic as shown in Figure 1

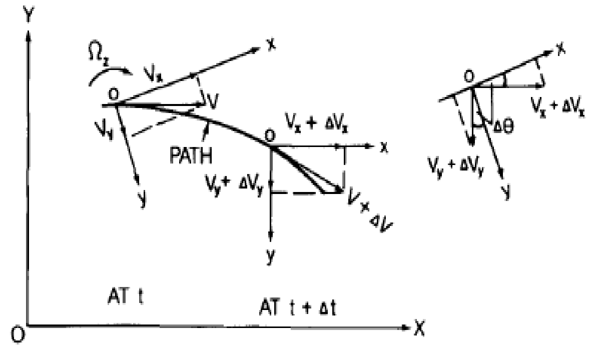

FIG.1 ANALYSIS OF PLANE MOTIONS OF A VEHICLE

Here, to formulate the equations of transient motion for a vehicle during a turning maneuver, absolute acceleration of the center of gravity of a vehicle need to be expressed.

As the vehicle is in both translation and rotation during a turn, which the time given is as $t + \Delta t$, the direction and magnitude of the velocity of the center of gravity are oriented with longitudinal and lateral axes of the vehicle change (as in figure above). The change of the velocity components parallel to the OX axis as given below:

$$(V_x + \Delta V_x)\cos\Delta\theta - V_x - (V_y + \Delta V_y)\sin\Delta\theta =$$
$$V_x \cos\Delta\theta + \Delta V_x \cos\Delta\theta - V_x - V_y \sin\Delta\theta$$
$$+ \Delta V_y \sin\Delta\theta \quad \text{.............} \quad (1)$$

Make $\Delta\theta$ small and neglect second order terms and the equation will be as

$$\Delta V_x + \Delta V_y \Delta\theta \quad \text{...............} \quad (2)$$

The components along the longitudinal axis of the absolute acceleration of the center of gravity of the vehicle can be obtained by dividing the above equation with Δt

$$a_x = \frac{dV_x}{dt} + V_y \frac{d\theta}{dt} = \dot{V}_x - V_y \Omega_z \quad \text{..............} \quad (3)$$

Following the same concept, the component along the lateral axis of the absolute acceleration of the center of the vehicle a_y is

$$a_y = \frac{dV_y}{dt} + V_x \frac{d\theta}{dt} = \dot{V}_y - V_x \Omega_z \quad \text{...............} \quad (4)$$

For vehicle having plane motion, the equations of motion with respects to the axes fixed to the vehicle body are:

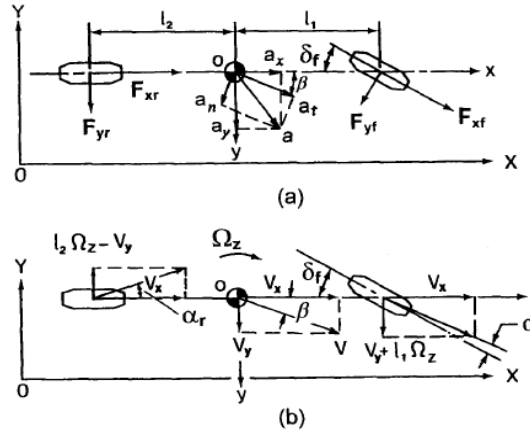

FIG.2 BICYCLE MODEL FOR TRANSIENT MOTION ANALYSIS

$$m\left(\dot{V}_x - V_y \Omega_z\right) = F_{xf}\cos\delta_f + F_{xr} - F_{yf}\sin\delta_f \quad \text{.......} \quad (5)$$

$$m\left(\dot{V}_y - V_x \Omega_z\right) = F_{yf}\cos\delta_f + F_{yr} - F_{xf}\sin\delta_f \quad \text{........} \quad (6)$$

$$I_z \dot{\Omega}_z = l_1 F_{yf}\cos\delta_f - l_2 F_{yr} + l_1 F_{xf}\sin\delta_f \quad \text{.......} \quad (7)$$

where I_z is the mass moment of inertia of the vehicle about the z axis.

It is assumed that the velocity body is symmetrical about the longitudinal plane, so the equation can be derived (xoz plane in Figure 2). In that case, the roll motion of vehicle body is neglected. The equation (5) can be neglected if the vehicle is not accelerated or decelerated along the OX axes. Hence, the yaw and lateral motions of the vehicle are governed by equation (6) and (7).

The slip angles such as a_f and a_f can be defined in terms of the vehicle motion variables Ω_z and Ω_y. By referring to the Figure 2b, angle assumption which is in small scale can be made.

$$a_f = \delta_f - \frac{l_1\Omega_z + V_y}{V_x} \quad \text{..............} \quad (8)$$

$$a_r = \frac{l_2\Omega_z - V_y}{V_x} \quad \text{..............} \quad (9)$$

The lateral forces acting on the front and rear tires are a function of the corresponding slip angle and cornering stiffness.

$$F_{yf} = 2C_{\alpha f}\alpha_f \quad \text{...............} \quad (10)$$

$$F_{yr} = 2C_{\alpha r}\alpha_r \quad \text{...............} \quad (11)$$

By the assumption that the F_{xf} is zero and the steer angle is a small value, the equations of lateral and yaw

motions of a vehicle with the steer angle as the only input variable become:

$$m\dot{V}_y + \left[mV_x + \frac{2l_1C_{\alpha f} - 2l_2C_{\alpha r}}{V_x}\right]\Omega_z + \left[\frac{2C_{\alpha f} - 2C_{\alpha r}}{V_x}\right]V_y = 2C_{\alpha f}\delta_f(t) \quad \text{.......} \quad (12)$$

$$I_z\dot{\Omega}_z + \left[\frac{2l_1^2C_{\alpha f} - 2l_2^2C_{\alpha r}}{V_x}\right]\Omega_z + \left[\frac{2l_1C_{\alpha f} - 2l_2C_{\alpha r}}{V_x}\right]V_y = 2l_1C_{\alpha f}\delta_f(t) \quad \text{.......} \quad (13)$$

In the above equation, $\delta_f(t)$ represents the steer angle of the front wheel as a functions of time. The dynamic model used in this research is simple model called as "Bicycle Model" as shown Figure 2 with the assumption as follows:

(i) Turning radius is equal to wheelbase of the vehicle.
(ii) Left and right steering angles are equivalent.
(iii) Left and right side slip angles of wheels are equivalent.
(iv) Friction and wind force are neglected.
(v) System is in a linear model.

Simulation Model

From the equation provided above, a simulink model has been developed. The final equation of the transient response, which are equation (12) and (13), were used for the simulink model development.

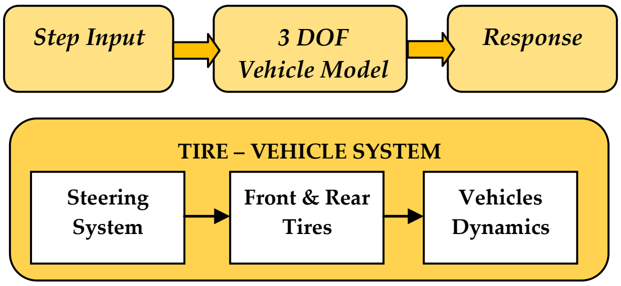

FIG. 3 DEVELOPMENT OF SIMULINK MODEL

This model, as shown in Figure 3, is used to develop the simulink model for the small scaled vehicle (Lukowski & Ravikumar, 1993; Putnam & Knapp, 1996). There were two condition tests implemented in this simulink model. The first one was the 30 degrees step steering input test, while the second test was double lane change test at 30 km/h according to the ISO 3888 standard. The response is obtained in a graphical method.

Parameter for Dynamic Modeling

In this model, the parameters used were based on the scaled vehicle model for the step steer test and double lane change test. Table 1 shows the parameter needed for this transient model.

TABLE 1: SMALL SCALE PARAMETERS

Handling Transient Parameters	Values
Distance of sprung mass C.G. from front axle, l_1 (m)	0.2326m
Distance of sprung mass C.G. from front axle, l_2 (m)	0.2874m
Vehicle mass, m (kg)	9.31kg
Front tire cornering stiffness, C_{af}	34.0 N/rad
Rear tire cornering stiffness, C_{ar}	45.0 N/rad
Moment of Inertia, *Iz*	0.8310
Longitudinal speed, *Vx* (m/s)	50km/h and 30km/h
Steering angle, δ_f (degree)	30º

The longitudinal velocity, *Vx*, was different for two experiments. For the step steer test, the 50 km/h is used as the longitudinal speed and 30 km/h for the double lane change test. A steering input of 30 degrees angle was given for the small scale vehicle.

Overall Operating System

The testing on the small scaled vehicle proceeds with certain equipments. Due to this is a small scaled vehicle, a human driver input is not required. A racing car used in this testing was with the weight around 9 kg and equipped with remote controller so that the vehicle can be controlled in a distance range.

Remote Control Racing Car

The remote control racing car as a scale model, shown in Figure 4, is chosen as an experimental platform. This model have the basic equipment, where the engine used is the single piston cylinder with two stroke engine.

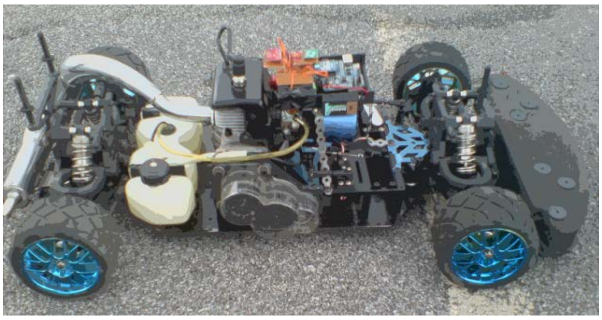

FIG. 4 REMOTE CONTROL RACING CAR

This racing car is also equipped with the petrol tank which needs petrol, 2T oil to lubricate the two stroke engine, exhaust pipe, motors, and the receivers to give

the steering and throttle input from the radio control transmitter.

Sensors Configuration

(i) Sensors are tested on breadboard and strip board using USB cable:

(a) First, the sensors are carefully identified by reading the manual for the sensors before use.

(b) After the specification checking, solder the both sensors on a strip board with the jumpers.

(c) Connect the sensors to the Arduino Microcontroller and the breadboard. Check with the multimeter for errors and short circuit.

(d) After connect to the laptop using USB, the program is uploaded using the Arduino software.

(e) After upload, the serial monitor is opened in the arduino software.

(f) Here the results are obtained for lateral acceleration, longitudinal acceleration and yaw rate.

(g) Then, all the connection is transferred from the bread board to strip board by solder on the board.

(h) Repeat the same step as above to check the connection of the sensors so that the output will be same as before.

(i) All this process took place using the USB cable connection to the Arduino microcontroller.

(ii) Sensor function is tested using the wireless connection device, XBee module.

FIG. 5 ARDUINO RECEIVER COONECT TO LAPTOP

a) Two Arduino microcontrollers are needed to complete the testing on sensors.

b) First, stack XBee wireless device on top of the Arduino microcontrollers.

c) There are two types of XBee device, which are transmitter (*transmit signal data from one point to another point*) and receiver (*receive signal data from transmitter*)

d) The transmitter is connected to the sensors using 9V battery and the receiver connected to the laptop using USB cable.This transmitting and receiving data are also called as Data Acquisition System.

e) Connect arduino with XBee transmitter to the USB cable before the connection to 9V battery.

f) Then, upload the program using arduino software (*do not remove the chip inside the arduino microcontroller*).

g) Remove the cable from the arduino and connect with the 9V battery.

h) The arduino receiver is connected with the USB cable through the laptop (*do remove the chip to avoid the signal clashing during data received from transmitter*).

i) Place the arduino transmitter 100 meters away from the arduino receiver (*follow the specification for XBee device*).

j) Run the program in the arduino software and check the results obtained from the serial monitor.

k) Shake the sensors to get the changes in the output results.

l) Place the sensors at the center of mass of the smart vehicle and start the experiment.

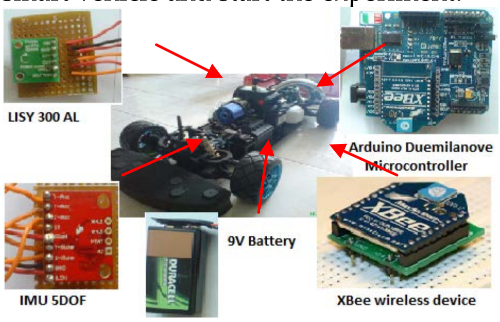

FIG. 6 SENSORS AND OTHER EQUIPMENT IN SCALE VEHICLE

Sensor Location on Scale Vehicle

All the sensors and the equipment are fixed into a small box which can hold all the experiment equipments. This will be fixed to the center of mass of the scale vehicle to obtain the results. There is a supporting system known as mounting system around the center mass to reduce and/or avoid the vibration of the engine.

Experiment

The sensor configuration is developed as the part of the experiment setups. All the sensors and other equipments are fixed to the center mass of the scale vehicle as shown in Figure 4. Here, human will control the scale vehicle by giving the steering input using the remote control. The signal input from the human will be received by the scale vehicle using the RF design

done for the scale vehicle.

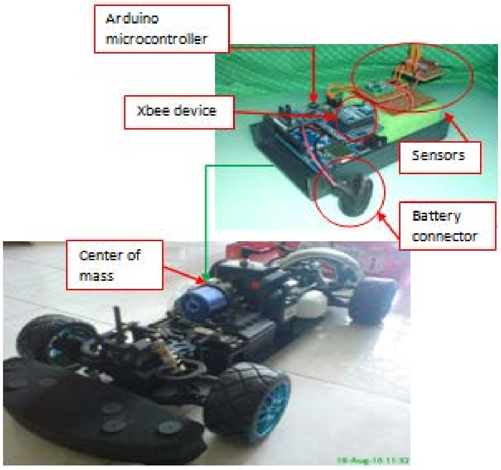

FIG. 7 DESIGN LOCATION FOR TEST EQUIPMENT

There are two experiments conducted by the human operator. The first experiment is the step steer test. For this experiment, an angle of 30 degree given as the steering input which will be direct the front wheels. The track has been prepared according to the Figure 8.

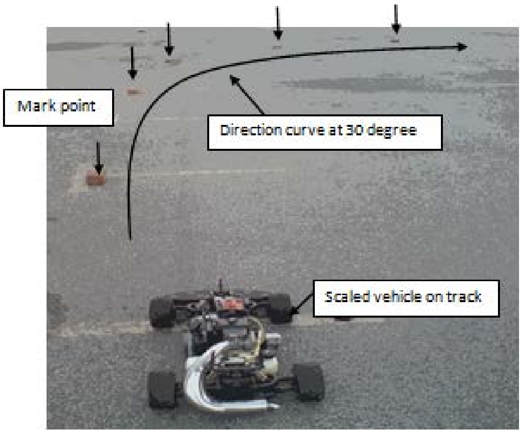

FIG. 8 SCALE VEHICLE ON TRACK FOR STEP STEER TEST

The distance to conduct this experiment is 100 m-200 m. The scale vehicle accelerates from 0 m/s² till to 50 km/h or 13.88 m/s. Once reaching the constant speed, the 30 degree steering input is given to the scale vehicle.

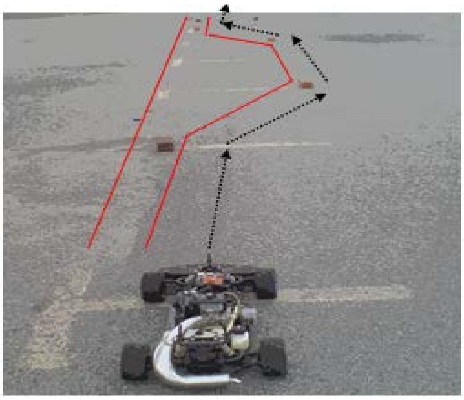

FIG. 9 TRACK COORDINATES FOR DOUBLE LANE CHANGE TEST

The second experiment is the double lane change test. The track coordinates has been identified based on the ISO 3888 standard. The test takes place at speed of 30 km/h or 8.33 m/s. The scale vehicle accelerates to the constant speed and follows the track coordinates as Figure 9.

The results obtained from the both experiments send via wireless communication. The wireless device, xbee device send the signal data to xbee device stack to arduino which is connected to laptop. The results will be displayed in the Arduino software using the serial monitor. The data has been saved using another software known as realterm. The results were saved in microsoft excel and used to make comparison with simulation results.

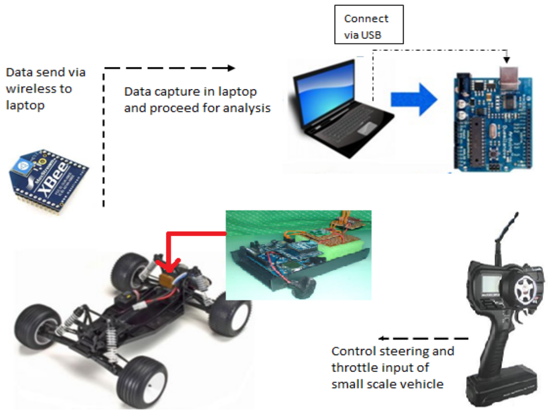

FIG. 10 OVERALL CONTROL SYSTEM

Results

Based on the experiment described, the output results obtained from the both final experiments were the yaw rate and the lateral acceleration. The results data obtained was in the deg/s, then converted in the m/s² for lateral acceleration and yaw rate in rad/s². Due to the data having a noise and disturbance, therefore the additional filtering algorithms need to be applied.

Figure 11 to 14 show that the results from both experiments and simulation were validated with the additional software CarSimEd.

(a) Step Steer Test

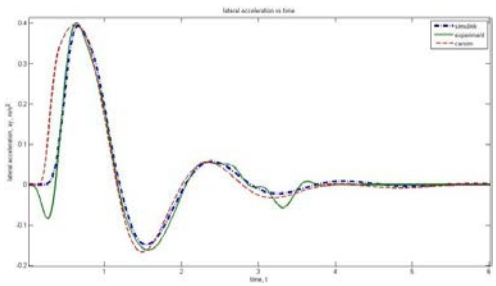

FIG. 11 LATERAL ACCELERATION VS TIME

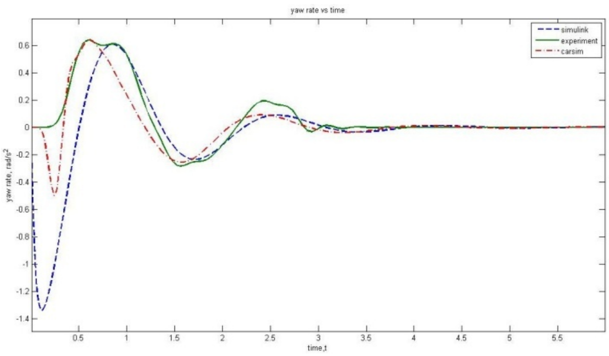

FIG. 12 YAW RATE VS TIME

(b) Double Lane Change Test

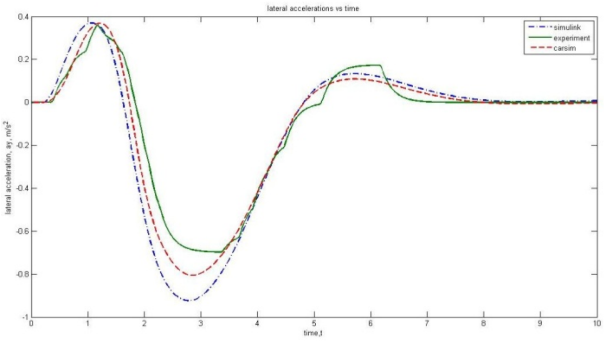

FIG. 13 LATERAL ACCELERATION VS TIME

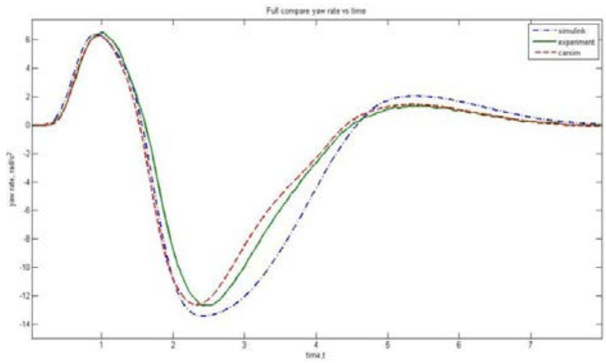

FIG. 14 YAW RATE VS TIME

The lateral acceleration and yaw rate from sensors, simulation and CarSimEd have the similar trends, but with slight deviation on the magnitude due to the external disturbance and degree of freedom consideration

Conclusions

This paper presents the development of the Sensor Configuration for Small Scale Autonomous Ground Vehicle. The cornering stiffness of front and rear scale vehicle is adjusted to have dynamic similarity to the real vehicle. The simulation results are adjusted according to the experiment results and validated with CarSimEd. The results have been consistent with the model. However, minor deviation occurred during the experiment and need to be improved in further research.

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